Geomorphology of Headless Submarine Canyons: Prediction of Slope Failure, Sediment Strength and Pore Pressure Gradient, and the Regular Spacing of Submarine Canyons

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Long Term Goal

The long term goal of this project is to understand the interaction between tectonic and hydrologic forcing and the resultant creation and modification of seafloor geomorphology.

Scientific or Technological Objectives

The initial objective of this project was to ground-truth the hypothesis that there is a causative relationship between geomorphology and fluid expulsion at the seafloor. Once that relationship was established, we sought to determine the hydrologic and geotechnical state of the venting and non-venting regions. The hydrologic and geotechnical data can be used together with the seafloor observations to model slope failure.

Background

The processes of accretion and tectonic compaction in active margins, and sediment loading and aquifer forcing in passive margins, lead to the expulsion of pore fluids and the generation of above-hydrostatic pore pressure gradients. These gradients affect the force balance of sediments at the seafloor via seepage force, and, if high enough, can destabilize a slope. When the material on a slope fails, the head gradient at the base of the failure will increase due to the decreased path length, and therefore the probability of failure increases within the pre-existing scar. This positive feedback will lead to the headward erosion of a canyon, resulting in the characteristic "headless" morphology of these features. Because the canyon imposes an indentation on the previously uniform constant head boundary at the seafloor, continued fluid expulsion will be attracted to canyons (and directed away from intervening regions). It is this hypothesis that we explored during the 1993 ALVIN program.

Approach

In order to study the interaction of tectonics and hydrology we are using a combination of field work, modeling, and geotechnical and hydrological analysis. First, we used a USGS deep tow video and camera sled and the ALVIN submersible in the fall of 1993 to make direct observations of fluid venting in and around canyons on the Oregon margin. These fluid vents (cold seep communities) are comprised of unique faunal assemblages that can be used to infer the distribution of fluid expulsion on the margin. Once we determined the location of the cold seeps, we then used ALVIN to deploy the deep ocean piezometers (Portable In-Situ Pore Pressure Instruments, or PISSPIs) for measuring pore pressure gradients both within vent sites and between vent sites. The PISPPI development and construction was supported by ONR as part of this project and carried out by Bobb Carson, Lehigh University. These instruments can be deployed in up to 4000m of water, are capable of measuring very small pore pressure gradients in the top 1m of the seafloor, and were deployed in deep water for the first time as part of our 1993 ALVIN field program. In addition to the hydrologic data, we also collected sediment push-cores at all of the PISSPI sites (both venting and non-venting) for later geotechnical analysis. We are now using our observations and analyses to model the creation of headless submarine canyons and their temporal and spatial evolution.

Accomplishments and Results

The Atlantis II/ALVIN program conducted in September, 1993 was successful in identifying cold seeps, determining their distribution, and measuring pore pressure gradients within and

between the cold seeps. We identified four cold seeps; all cold seep sites were within canyons, and none were found along strike between canyons (Figure 1).

Even though all fluid seeps were found in canyons, not all canyons had seeps, and the location of the seeps within the canyons differed on the landward and seaward limbs of the anticlines (Figure 2). This suggests both spatial and temporal variations in fluid flow. On the landward limb of the second landward vergent anticline a robust cold seep community occurs at the base of the steep canyon headwall. The seep is characterized by chemoautotrophic vent clams (Calyptogena and Solemya), Vestimentiferan tube worms, and extensive authigenic carbonate. Fluids for this seep may utilize flow paths either parallel to bedding in the hanging wall of the second thrust ridge, or may travel along the underlying thrust fault itself. Two seaward facing canyons on the third landward vergent ridge have vent clam communities (Calyptogena, scattered Solemya) at a different location, namely the base of the canyon near the canyon mouth (the intersection between the anticlinal ridge and the adjacent forearc basin). No seeps were found along strike at the intersection of the slope basin and anticlinal ridge. Fluids for these seeps may originate in the section beneath the second landward vergent thrust, utilize stratigraphic conduits, and may be prevented from venting in the forearc basin by a basal unconformity.

The presence of authigenic carbonate on the second ridge canyon seep, but not the third ridge, may be attributed to a difference in fluid source. Carbonate precipitates from the oxidation of methane, whereas clam and tube worm colonies require hydrogen sulphide for survival; Vestimentiferan tube worms are thought to require higher concentrations of sulphide than clams. The difference in seep fauna and carbonate suggests that the fluids supporting the robust seep at the inflection point of the headless canyon on the second landward vergent ridge may originate at deeper levels than the seep on the third landward vergent ridge.

At present we are analyzing the PISPPI data, and combining these data with sediment physical properties determined from the ALVIN push cores. The geotechnical portion of the program is being carried out with Homa Lee and Rob Kayen at the USGS Branch of Pacific Marine Geology. Our preliminary analysis suggests that the ambient pore pressure gradients at the sites of fluid venting are above hydrostatic, but below that required to initiate slope failure. If these measurements represent steady-state, than some transient pressure pulse must be required to initiate seepage-induced slope failure. We are exploring the possibility that seismicity or methane expulsion can produce the required transient.

Impact on Science, and Transitions Accomplished or Expected, If Any:

Orange has been approached separately by two oil companies (Chevron and PetroBras) to discuss the role of seepage force in triggering sediment slope failure. Both companies are exploring platform drilling in deep water on continental slopes, and are concerned over safety issues.

Relationship to Other Projects, if known:

The analysis presented above will be compared with the slope evolution model of Pratson, Coakley and Steckler in 1995. We hope to use the morphologic information (SeaBeam) and direct observations as inputs to Pratson et al.'s model. In addition, the hypothesis of seepage-induced spring sapping will be included in the slope failure/sedimentation models of Parker, Garcia, and Syvitski as part of the larger STRATAFORM research project. We anticipate that the observational basis for analyzing fluid-geomorphologic interaction will be directly applicable to southern Cascadia as part of the STRATAFORM Slope Working Group Field Program in 1995. Finally, the techniques that we are formulating for in situ hydrological and post-cruise laboratory geotechnical analysis will be applicable to the STRATAFORM analysis program planned for 1996.

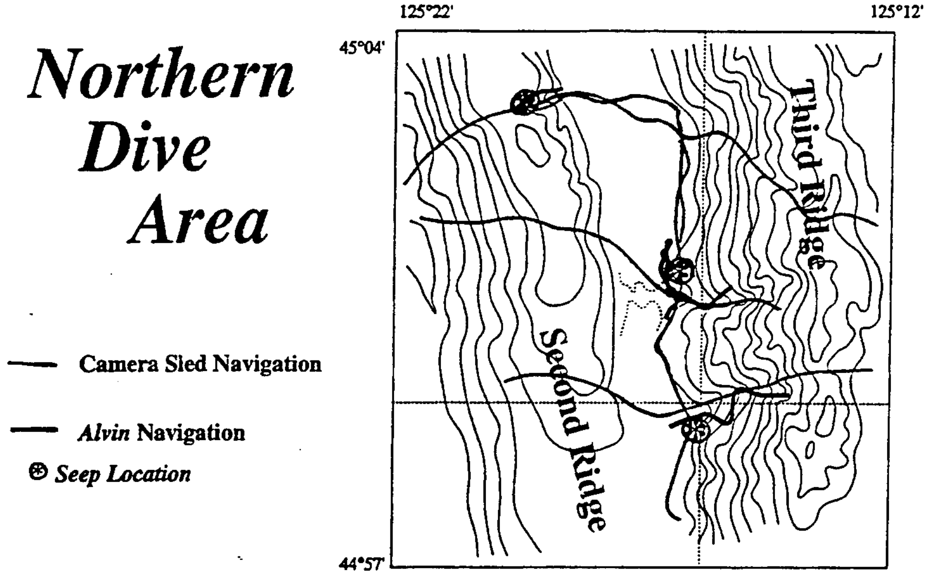

Figure 1: Detailed SeaBeam bathymetric map of the second and third anticlines and intervening slope basin on the landward vergent portion of the Cascadia accretionary complex. Note the extensive along strike surveys as well as the location of ALVIN dives within headless canyons. All cold seeps were located within the canyons, although their position within the canyons varies across the forearc basin.

Northern Dive Area- Line OR-25

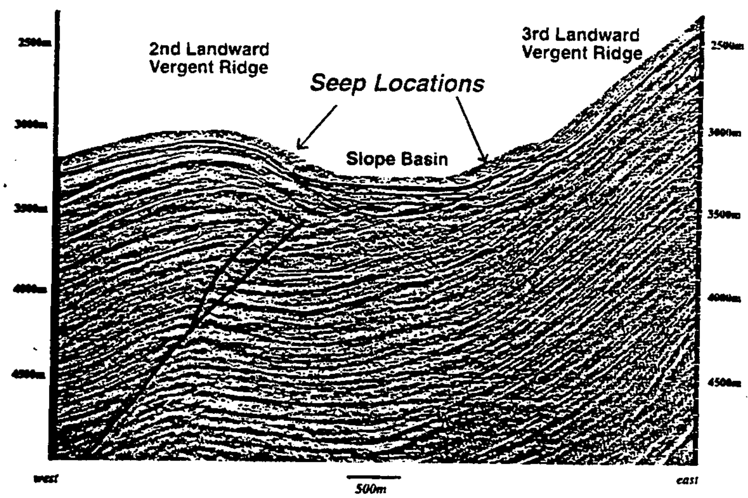

Figure 2: Migrated and interpreted MCS line OR-25 through the above area. Seeps on the landward limb of the second landward vergent ridge may be fed by fluid channeled along the thrust fault or stratigraphic conduits within the hanging wall section. Fluids seeping out on the seaward limb of the third anticlinal ridge may be stratigraphically controlled and prevented from venting in the forearc basin by a basal unconformity.

Statistical Information:

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Publications:

Orange, D.L., Anderson, R. S., and Breen, N. A. (1994), Regular canyon spacing in the submarine environment: the link between hydrology and geomorphology, G.S.A. Today, v. 4, p. 29-39.

Oral presentations at scientific meetings/conferences (Fall, 1993 AGU to Fall, 1994 AGU).

Ferioli, L., Johnson, K., Orange, D., and Greene, G. (1994) In situ chemical characterization of cold seep fluid in the Monterey submarine canyon, to be presented at AGU annual meeting, San Francisco, December, 1994.

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Silver, E.A., Orange, D., Langseth, M., Gieskes, J., Abbott, L.D., Screaton, E., Kahn, L., McAdoo, B., Zulegar, E., Protti, M., You, C-F., Galewsky, J., and Ferioli, L. (1994) Importance of out-of-sequence thrusts as fluid conduits in the SW Costa Rica accretionary complex, EOS (Transactions, American Geophysical Union), v. 75, p. 324.

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Gieskes, J.M., You, C-F., Silver, E.A., Orange, D.L., Abbott, L.D., McAdoo, B., Galewski, J., Kahn, L.M., Ferioli, L., McIntosh, K.D., Screaton, E., Protti, M., Langseth, M. (1994) Chemistry of interstitial waters of ALVIN push cores (APC) in black, clam-hosting sediments: Costa Rica accretionary prism, EOS (Transactions, American Geophysical Union), v. 75, p. 242.

Orange, D.L., Greene, H.G., McHugh, C., Ryan, W.B.F., Reed, D., Barry, J., Kochevar, R., and Connor, J. (1993), Fluid expulsion along fault zones and mud volcanoes in Monterey Bay, EOS (Transactions, American Geophysical Union), v. 74, p. 242.

Greene, H.G., Orange, D.L., and Barry, J., (1993), Geologic diversity of cold seep communities, Monterey Bay region, Central California, U.S.A., EOS (Transactions, American Geophysical Union), v. 74, p. 578.

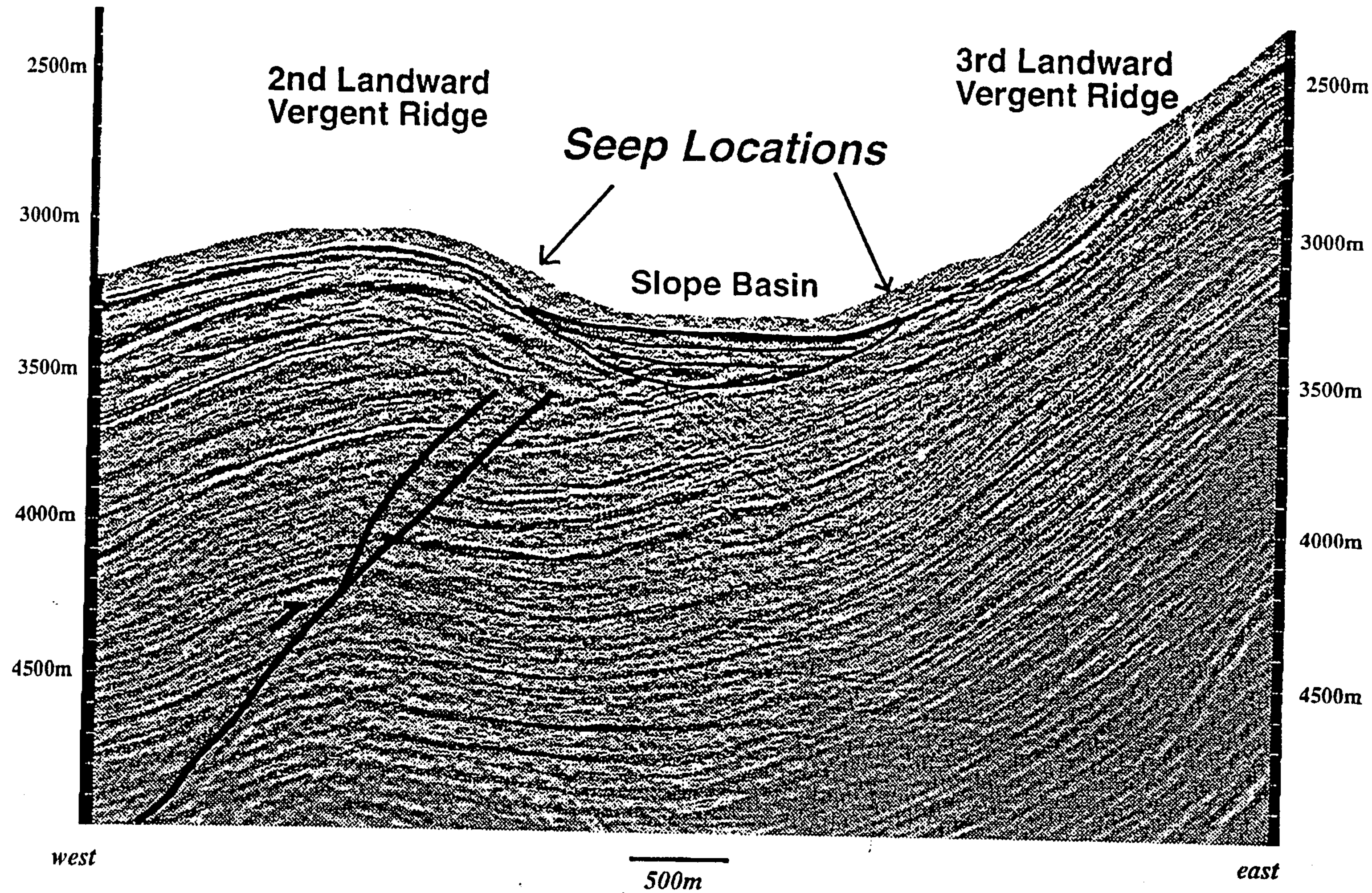
Orange, D.L., Anderson, R. S., and Breen, N. A. (1993), Regularly spaced submarine canyons: A proposed link between slope failure, hydrology and geomorphology, Geological Society of America Abstracts with Programs, v. 25, p. A60.

Graduate students:
2 Graduate Students (at University of California, Santa Cruz):
Brian G. McAdoo
Janet Yun

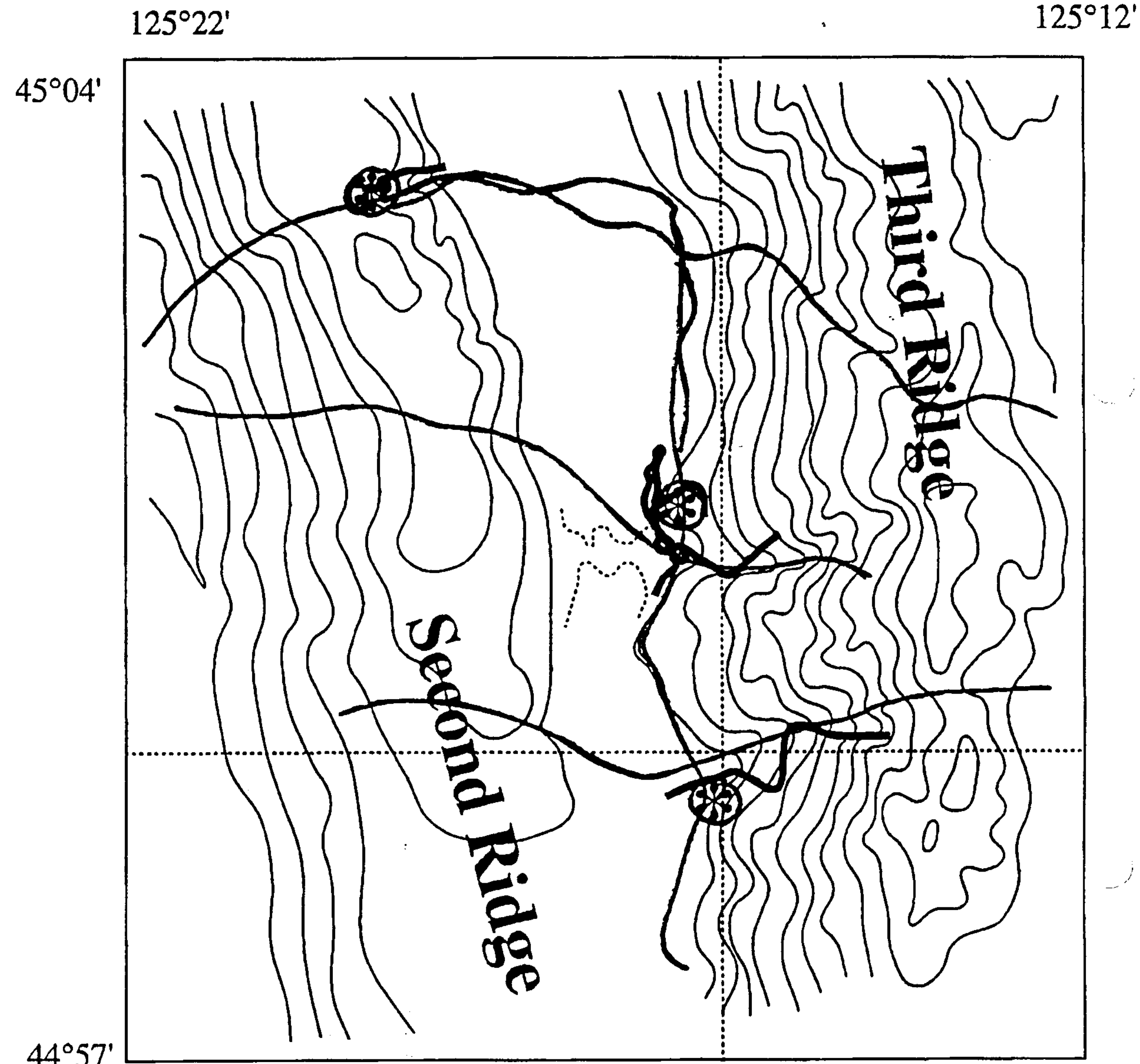
Number of female graduate students: 1
Number of minority graduate students: 2

Service on committees/panels:
DESSC (Deep Submergence Science Committee - formerly ALVIN review committee); 1993-1995
ONR STRATAFORM committee; Slope Working Group; 11/93 - present
Board of Directors, The Lyceum (a non-profit organization providing extracurricular education activities to primary and secondary school children in the Monterey-Salinas-Watsonville area); 9/94 - present

Northern Dive Area- Line OR-25



Northern Dive Area



Camera Sled Navigation

***Alvin* Navigation**

⊛ *Seep Location*